N65-88841
~~X63 15698~~

(NASA CR-51417)

Code 2A

6p

[1963] 10 ref. Submitted for Publication

[R]

SPECTROSCOPIC INVESTIGATION OF VENUS

Lewis D. Kaplan (Calif. Inst. of Tech.)
Jet Propulsion Laboratory, Pasadena

Space science, in particular the science of the solar system, ushered in the scientific renaissance. Today the success of Mariner II marks the beginning of a new renaissance of space science, one that promises to surpass the first in increasing man's understanding of the nature and history of our expanding part of the universe. Quantitative spectroscopy, particularly as applied to the analysis of planetary atmospheres, will play an extremely important role in this renaissance.

Our present knowledge of the composition of planetary atmospheres is deduced almost entirely from the observed rotational fine structure of the attenuation of sunlight. By such measurements, CO_2 was detected on Venus, NH_3, CH_4 and H_2 were found on the major planets, and many of the minor constituents in our own atmosphere were identified.

The arrival of the Space Age has accelerated the application of spectroscopy to atmospheric analysis. Continuous composition measurements will be made by observing the absorption of sunlight from orbiting satellites and flyby spacecraft. The interpretation of the measurements is relatively easy if the constituents are uniformly mixed and the light path known, but even in this case, the radiative transfer along the inhomogeneous path must be understood. If the atmosphere and its clouds scatter and reflect sunlight or if the relative composition varies with height, the interpretation of the measurements is more difficult and requires both an understanding of the spectrum and at least crude resolution of the absorption bands.

An exciting possibility, and one that will be used during this decade, is the analysis of the thermal structure of planetary atmospheres from measurements of their emission spectra as seen from outside the atmosphere. The shape of emission spectra is determined, for a given composition, by the variation of temperature with height. This height variation of temperature can be obtained, in principal, by inverting the radiative transfer equation.[1,2] This principle is now being applied to meteorological soundings from satellites by the U. S. Weather Bureau.[3]

Recent results of interpretation of Venus spectra illustrate the power of spectroscopy in atmospheric analysis. Venus is perpetually cloud-covered, and it seemed until very recently impossible to determine the characteristics of the atmosphere below the clouds. However, the analysis of spectra from earth-based observatories and from Mariner allows us to feel that we are beginning to understand the lower atmosphere of Venus.

Gk nu

~~CO_2~~ Carbon dioxide was detected in the Venus atmosphere by Adams and Dunham thirty years ago by the identification of lines in the $5\nu_3$ and $5\nu_3 + (\nu_1, 2\nu_2)$ bands.[4] It is the only molecule unambiguously identified. Many of the Adams and Dunham spectra were not reduced until very recently.

Emission spectra were taken by Strong and Sinton[5] and interpreted to give a cloud-top temperature of about 235° K.[6] Microwave measurements indicated temperatures of the order of 700° K, which were variously interpreted as surface temperature or temperature of a very dense ionospere. The difficulty in accepting such a high temperature as a surface temperature is obvious; an extremely efficient greenhouse effect is necessary to maintain it.

Even before the microwave measurements from Mariner, the difficulty appeared to be on the verge of resolution. Spinrad reduced and analyzed the best of the Adams and Dunham spectra and found rotational temperatures as high as 440° K.[7] He also measured line widths and obtained mean pressures as high as 5 atmospheres. A further analysis of these spectra led to the discovery of two sharp Boltzmann rotational maxima, one corresponding to about 300° K and the other to about 700° K.[8]

This not only indicated that the microwave emission is due to high surface temperature, but provided the clue for its explanation. The double maxima in rotational temperature distribution implies a stratified cloud layer at a level corresponding to a temperature of about 400° K. All molecules that are likely candidates for condensation or polymerization at this temperature have CH bonds, and therefore absorb strongly around 3.5 μ. This is the most important gap in the CO_2 and H_2O spectra for temperatures greater than 700° K, and must be closed to maintain such a temperature.

Gk mu

The high surface temperature was verified in an unambiguous manner by the Mariner microwave measurements.[9] The problem now is to account quantitatively for the very great opacity of the lower atmosphere by identifying the absorbing gases, determining their spectra, and calculating the heat balance.

The results of the Mariner infrared measurements[10], to the extent that they are verified by calibration studies now under way, provide an excellent example of the power of quantitative spectroscopy. The infrared radiometer was a spectrometer only in the most trivial sense, i.e., in that it had two channels. Moreover, the results of the wavelength discrimination were essentially negative; within the apparent measurement errors, the same radiation temperatures were read in both wavelength intervals. Yet the experiment provided significant information about Venus, and the significance resulted from the spectrometric character of the radiometer.

The channels were centered at an infrared window around 8.4 μ and in the $\nu_3 - \nu_1$ CO_2 band around 10.4 μ. The purpose of the experiment was to study the cloud structure by determining its opacity. A monotonic limb-darkening was obtained, with a 20° C gradient from sub-probe point to limb. The equality of the radiation temperatures as seen by both channels indicated that the radiation emanated from the cloud particles and that the deepest level "seen" was high enough in the atmosphere that the CO_2 absorption by the overlying air was small. The amount of limb darkening puts an absolute lower limit of 2 or 3 km for the cloud depth; and the absence of CO_2 absorption for the vertical orientation implies that it is much deeper, because even a very small fraction of ground radiation penetrating the clouds would have indicated a marked difference in the radiation temperatures due to strong absorption in the 10.4 μ channel relative to that in the 8.4 μ channel. The radiation temperatures measured at the limbs were about 220° K; this is an upper limit for the temperature at the cloud top.

The Mariner infrared results show that broad band radiometry can be used for sounding the Venus clouds in our 10 μ atmospheric window, provided the long-wave cutoff is shortward of strong Venus CO_2 absorption beginning at about 13.5 μ and proper correction is made for attenuation by our atmosphere. However, during the next few years most of the new information about the structure of Venus' atmosphere will come from really quantitative spectroscopy.

A

Sm Type throughout

References

1. L. D. Kaplan: J. Opt. Soc. Amer., 49, 1004 (1959).
2. L. D. Kaplan: J. Quant. Spectrosc. Radiat. Transfer, 1, 89 (1961).
3. M. G. Dreyfus and D. T. Hilleary: Aerospace Engineering, 21, 42 (1962).
4. W. S. Adams and T. Dunham: Publ. Astron. Soc. Pacific, 44, 423 (1932).
5. J. Strong and W. M. Sinton: Astrophys. J., 131, 460 (1960).
6. L. D. Kaplan: Planet. Space Sci., 8, 23 (1961).
7. H. Spinrad: Publ. Astron. Soc. Pacific, 74, 187 (1962).
8. L. D. Kaplan: Mem. Soc. Roy. Sci. Liège, 7, Contrib. 28 (1963).
9. F. T. Barath, A. H. Barrett, J. Copeland, D. E. Jones and A. E. Lilley: Science, 139, 908 (1963).
10. S. C. Chase, L. D. Kaplan and G. Neugebauer: Science, 139, 907 (1963).